Optimization-based Method for Road Network Extraction

Demin Xiong
Center for Transportation Analysis
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6206
xiongd@ornl.gov
(865) 574-2696

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Presentation Outline

1. Background
2. The Method
3. Experiment: Data, Analysis and Results
4. Conclusions and Discussions

Background

- Road map database is still a key element that impacts an array of transportation applications, including ITS, transportation planning, road construction, maintenance, etc.
- Nevertheless, transportation networks change rapidly (new constructions, road improvement and change of road characteristics). This makes data maintenance and update difficult.
- The increasing availability of high resolution images (IKONOS and ORTHOPHOTOS) make image data an attractive solution to road network data problem.
- The purpose of the current research is to explore automated approaches to extract road networks from high resolution images. This presentation particularly focuses on an optimization method for road recognition.

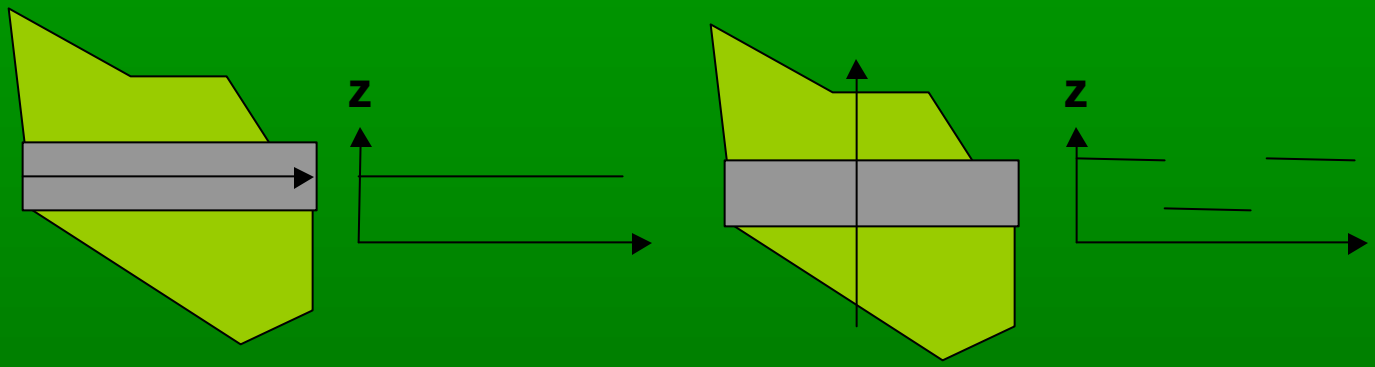
Existing Method

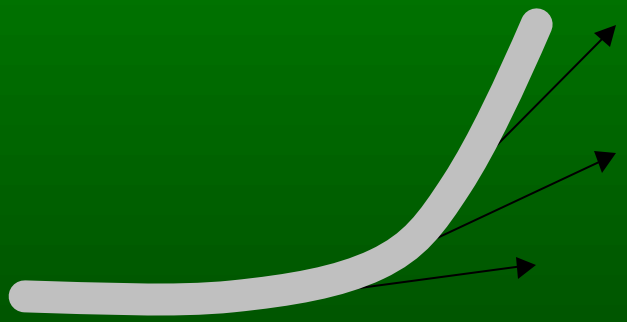
APPROACH	DESCRIPTION
Differential Geometry (Steger)	*Curve fitting, and road pixel linking.*
Gradient Direction Profile Analysis (Wang et al)	*Local gradient computing, ridge profiling, noise removing and ridge thinning.*
Map-Matching with Artificial Neural Networks (Fiset et al)	*Map matching for NN training and template matching for intersection and segment detection.*
Dynamic Programming (semi-automated) (Gruen and Li)	*Road model construction and dynamic programming.*
Geometric Stochastic Modeling (Barzohar & Cooper)	*Geometric probabilistic model construction and road finding with MAP (Maximum a Posteriori Probability).*
Active Testing (Geman and Jedynak)	*Tracking roads through statistical model construction and hypotheses testing.*
Integrated Approach (Zafiropoulos)	*Template matching and least square fitting with the use of techniques of deformable contour models.*

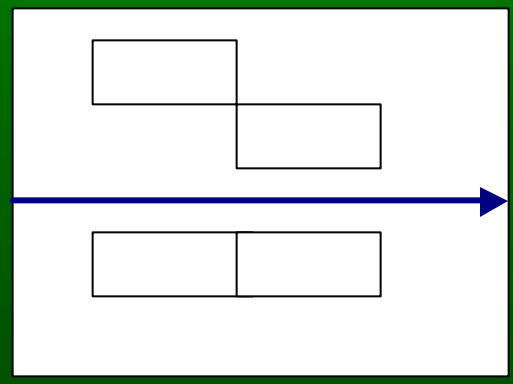
General Approach

- Low-level analysis characterizes images and extracts information on a pixel by pixel basis using only reflectance/emission measurements (e.g., filtering, edge detection, segmentation, etc.).
- Intermediate level analysis symbolizes and fuses low level results to form data structures for high level analysis. It includes primarily regional operations such as road tracking, region growing, connective component labeling, skeleton delineation, and so on.
- High level analysis involves not only imagery but domain specific knowledge, ancillary sources, and symbolized data from the intermediate level results to establish reliable interpretation

Optimization-based Road Model







Modeled Characteristics

- Smoothness along road segments

$$\min\ f(u) = \sum_{e \in E} \int_{0}^{Se} |dZ/du|\,du$$

- Drastic changes perpendicular to road sections

$$\min\ f(n) = 1/\sum_{e \in E} \int_{0}^{Se} |dZ/dn|\,du$$

Modeled Characteristics

- Angular regulations:

$$\min \mathbf{f}(y') = \sum_{e \in E} \int_{0}^{Se} |dq/ds| du$$

$$\min \mathbf{f}(y'') = \sum_{e \in E} \int_{0}^{Se} |d^2q/ds^2| du$$

- Overall formulation:

$$\min \mathbf{F}(v) = w_s f(s) + w_n f(n) + w_{y'} f(y') + w_{y''} f(y'')$$

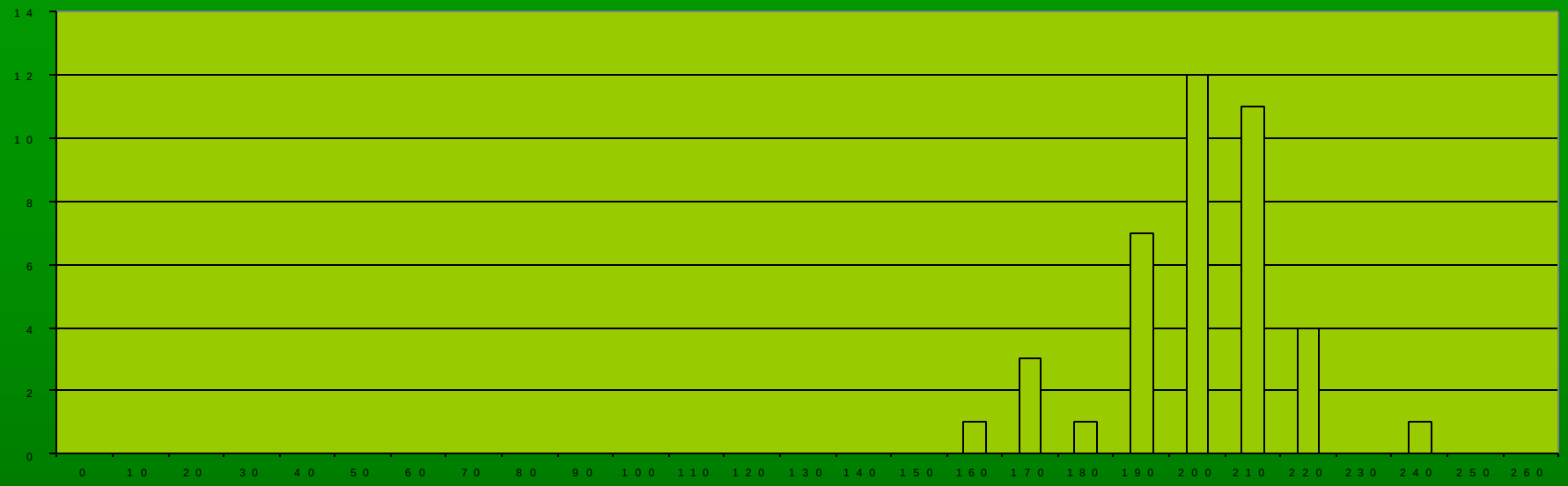
Recognition Mechanism

- Road search: the program first runs a template-matching procedure that localizes potential road pixels, followed with the optimization to identify potential road segments. To allow a more inclusive search, a relaxed road model is utilized during this search. After this search process, all segments found will be considered as a road candidate.
- Then the supervised ISODATA classification procedure is applied to identify whether a candidate is a road or not a road.

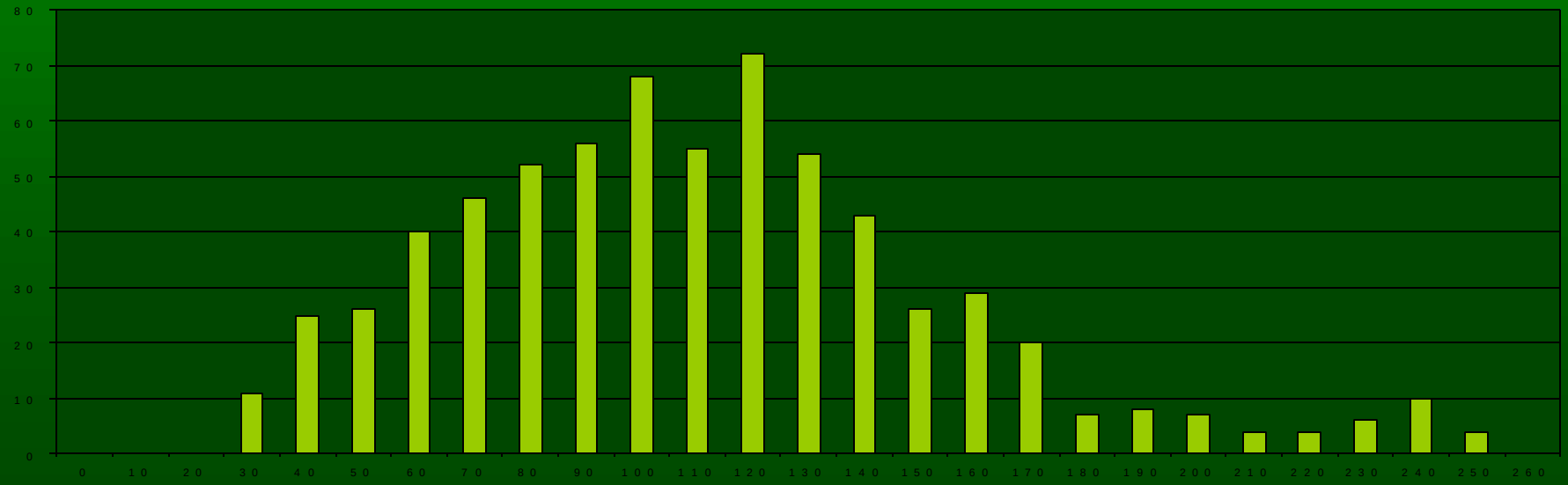
Experiment: Data, Analysis, and Results

- **Data**
  - 6 Inch Orthophotos from Hamilton County GIS Department
  - Manually extracted road networks
  - TIGER file

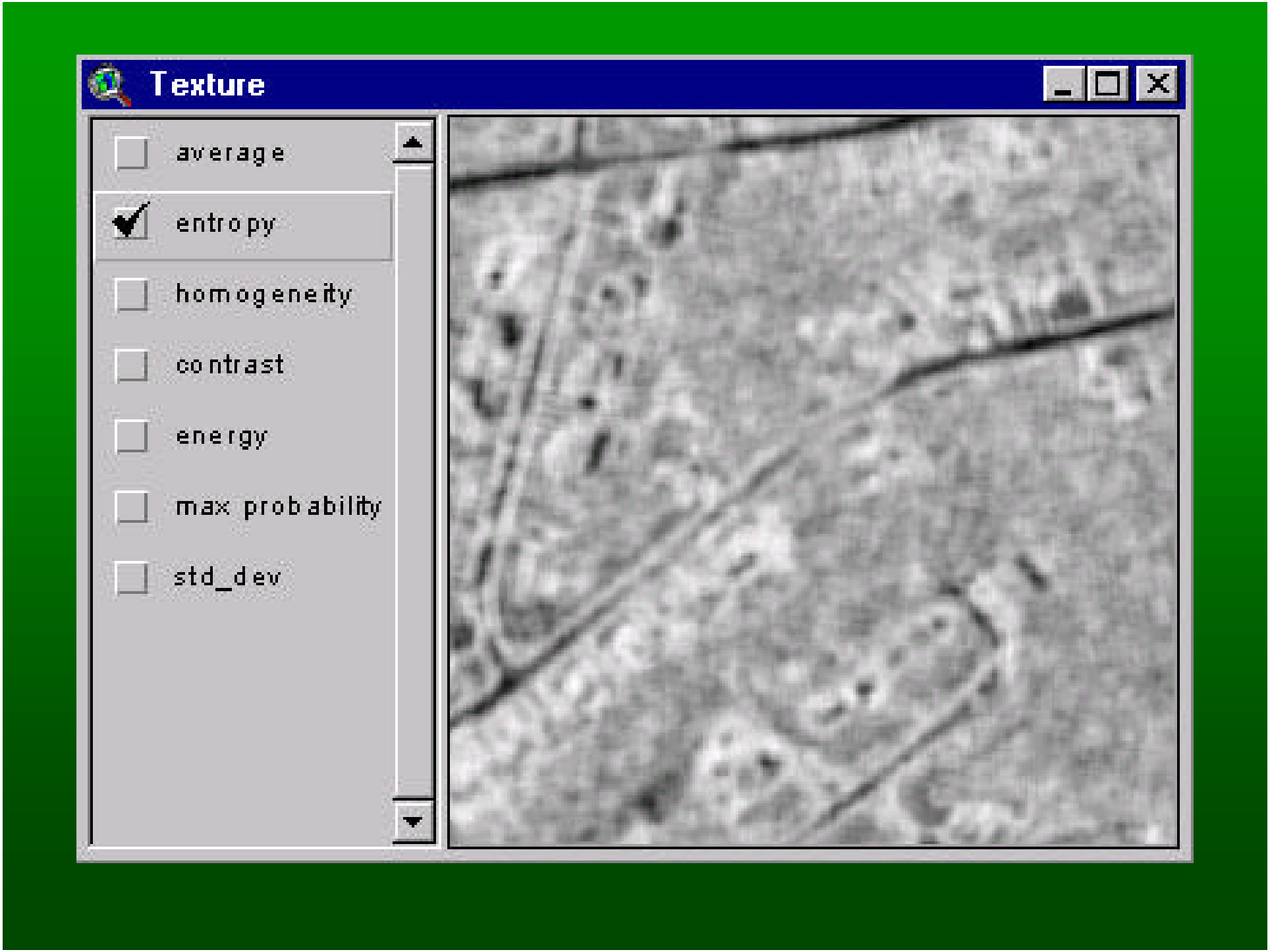

Texture
original image
average
entropy
homogeneity
contrast
energy
max probability
std_dev

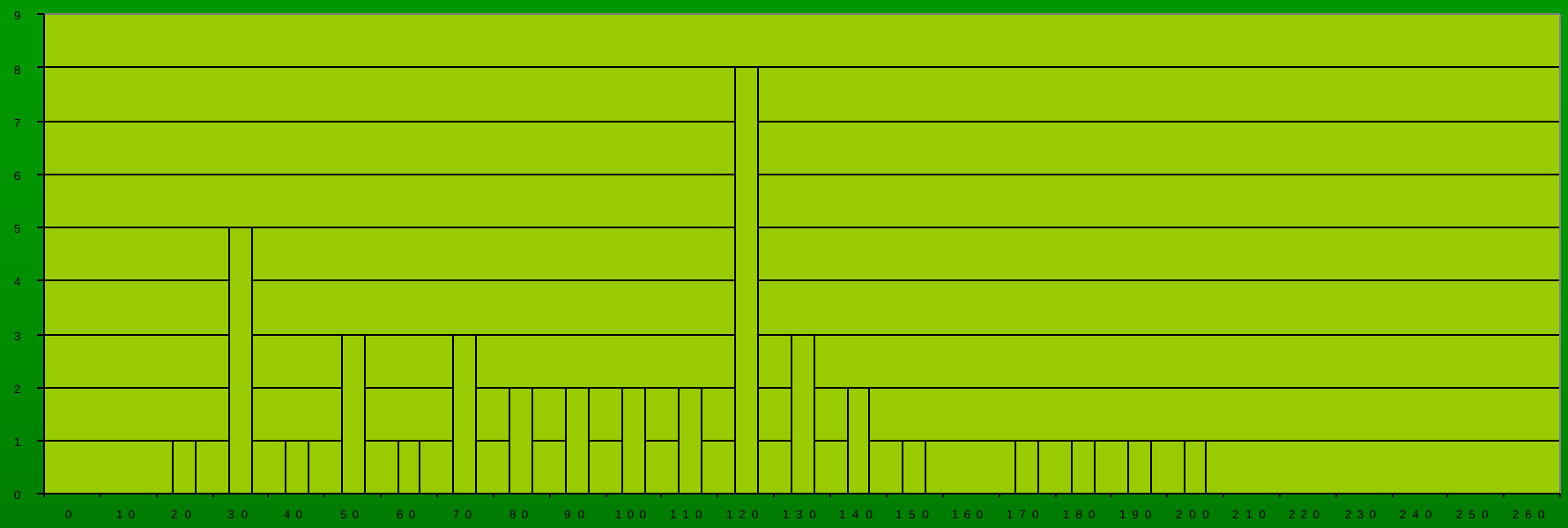


Intensity for On-Road Pixels

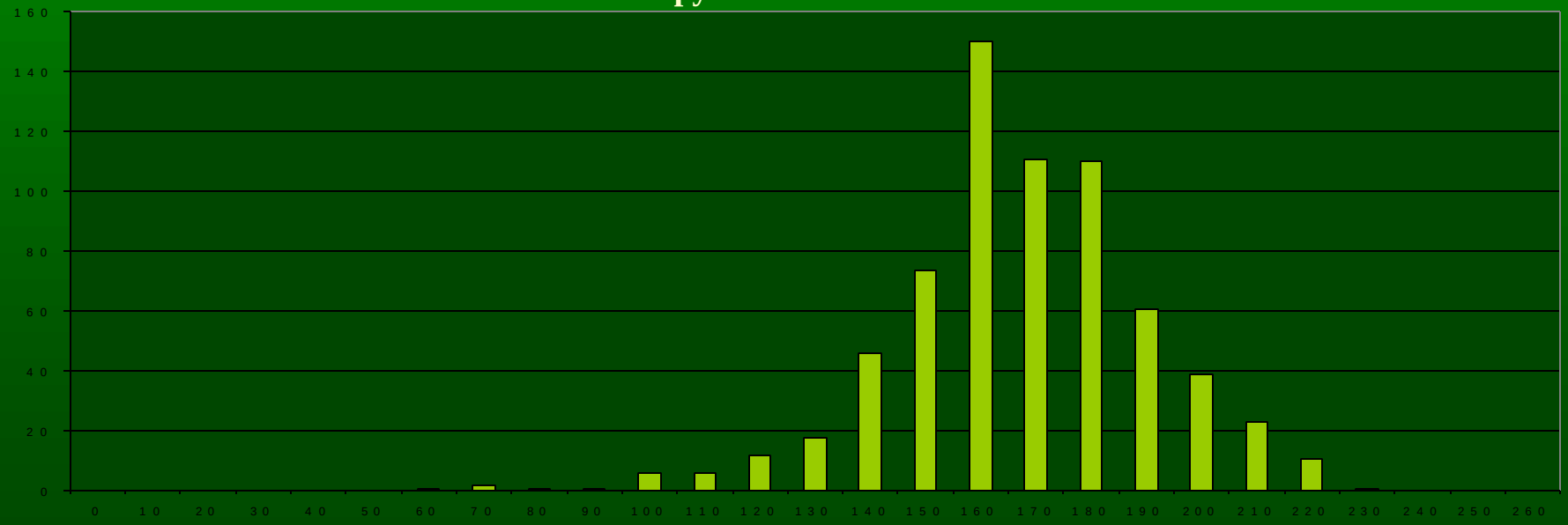


Intensity for Off-Road Pixels


Texture
average
entropy
homogeneity
contrast
energy
max probability
std_dev

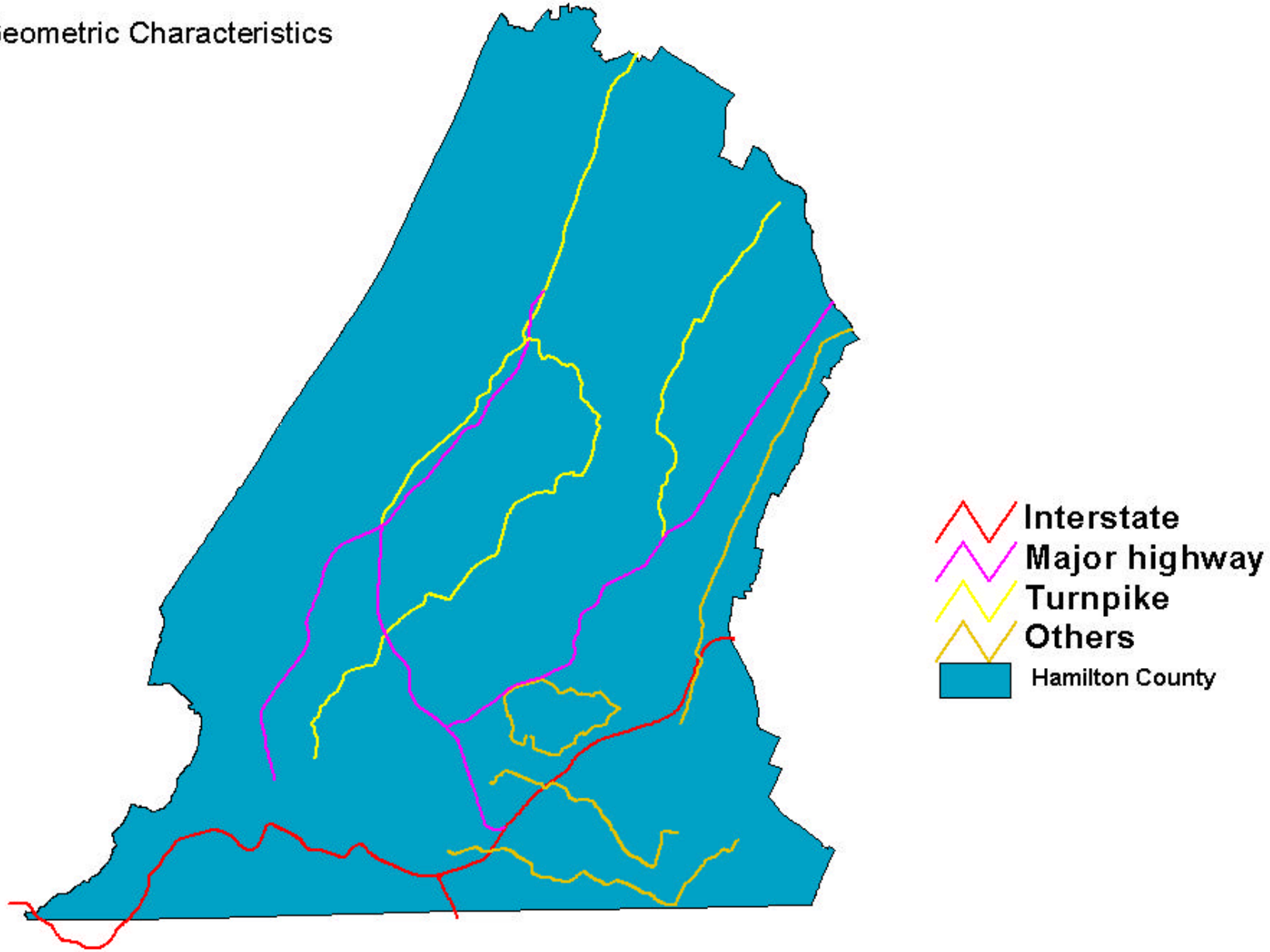


Entropy for On-Road Pixels

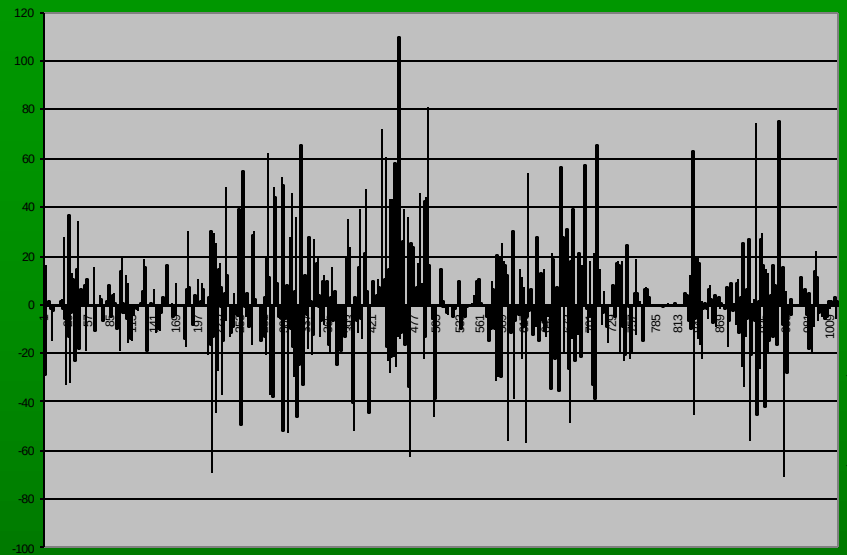


Entropy for Off-Road Pixels

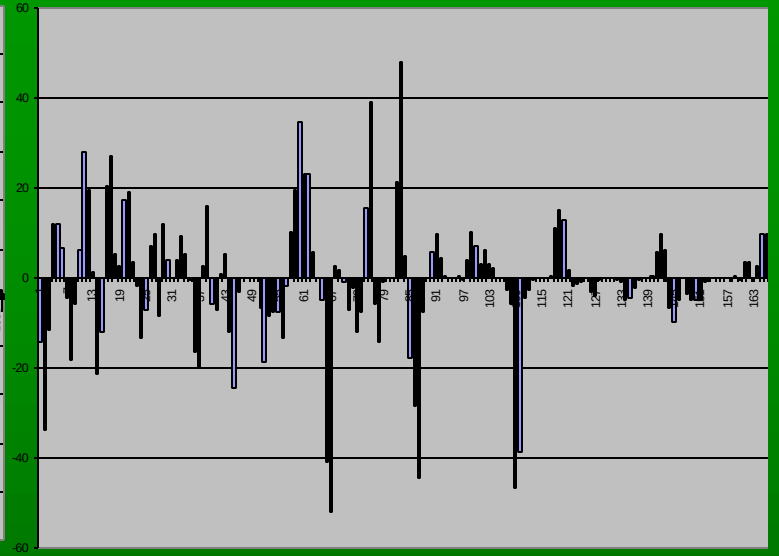
Geometric Characteristics



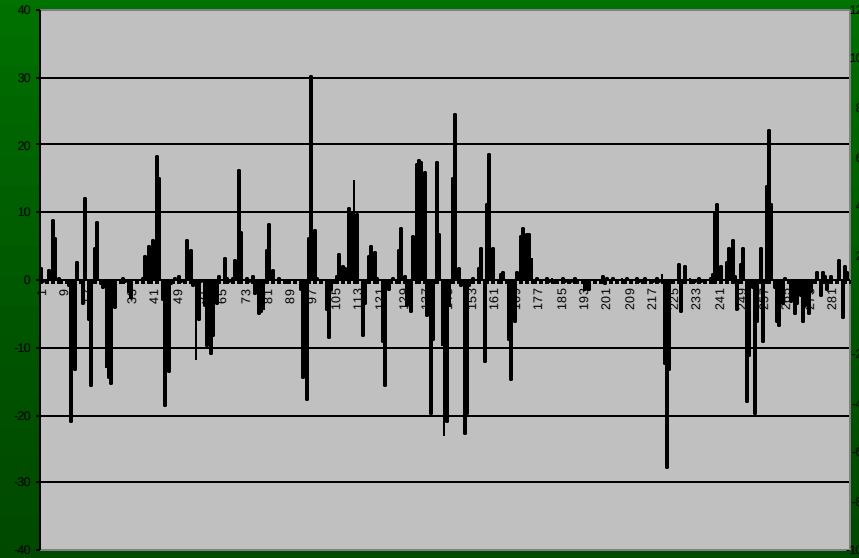
Characteristics of Road Directional Changes



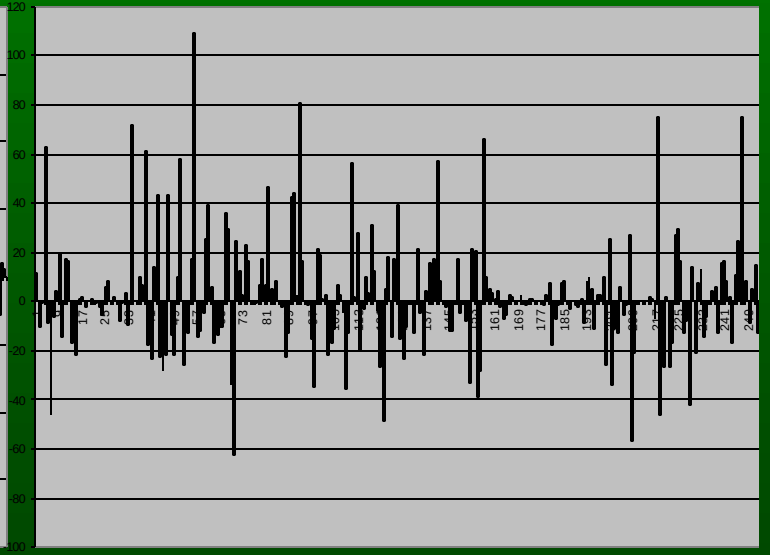
All the roads



Interstate

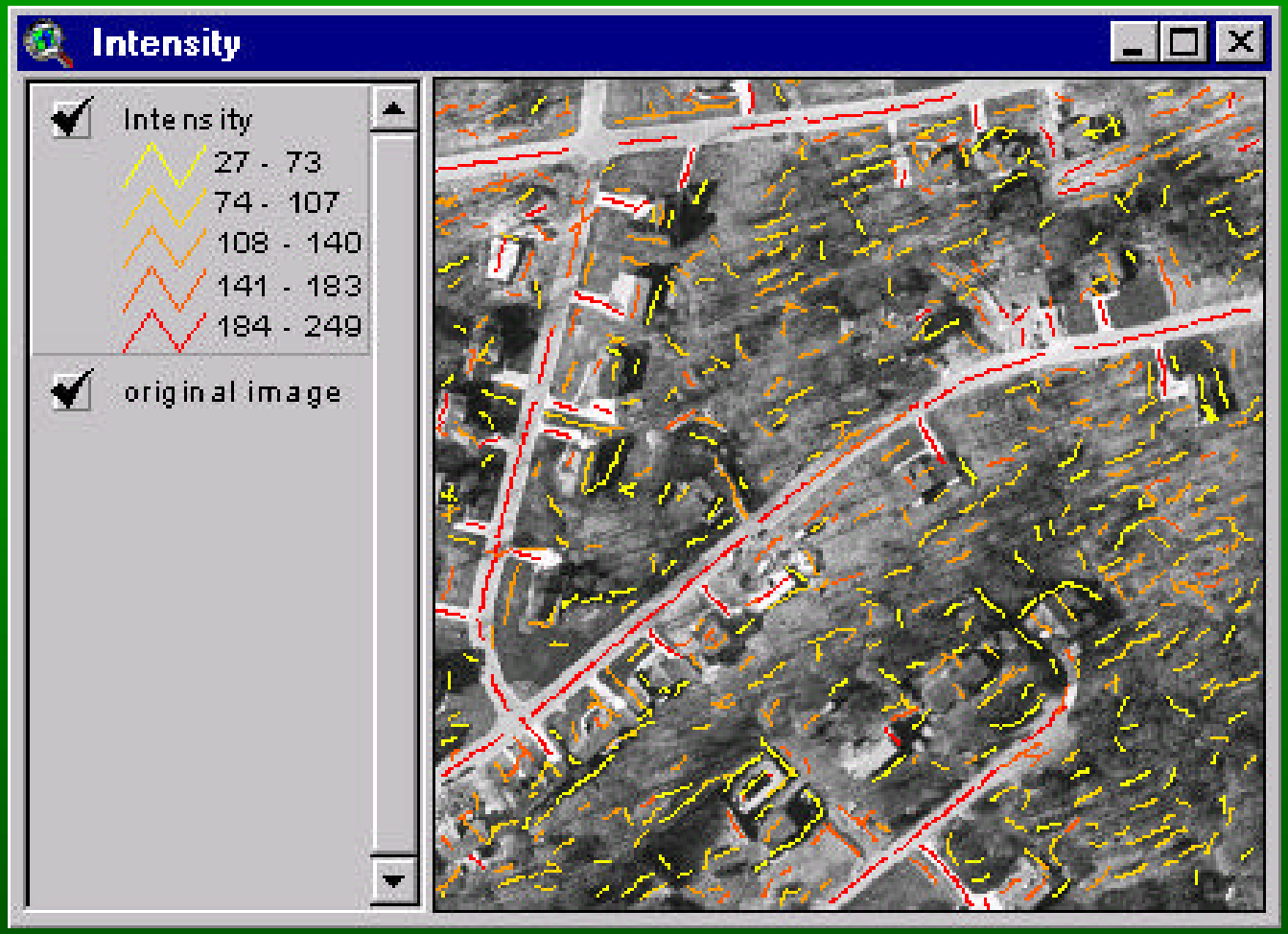


Major highways

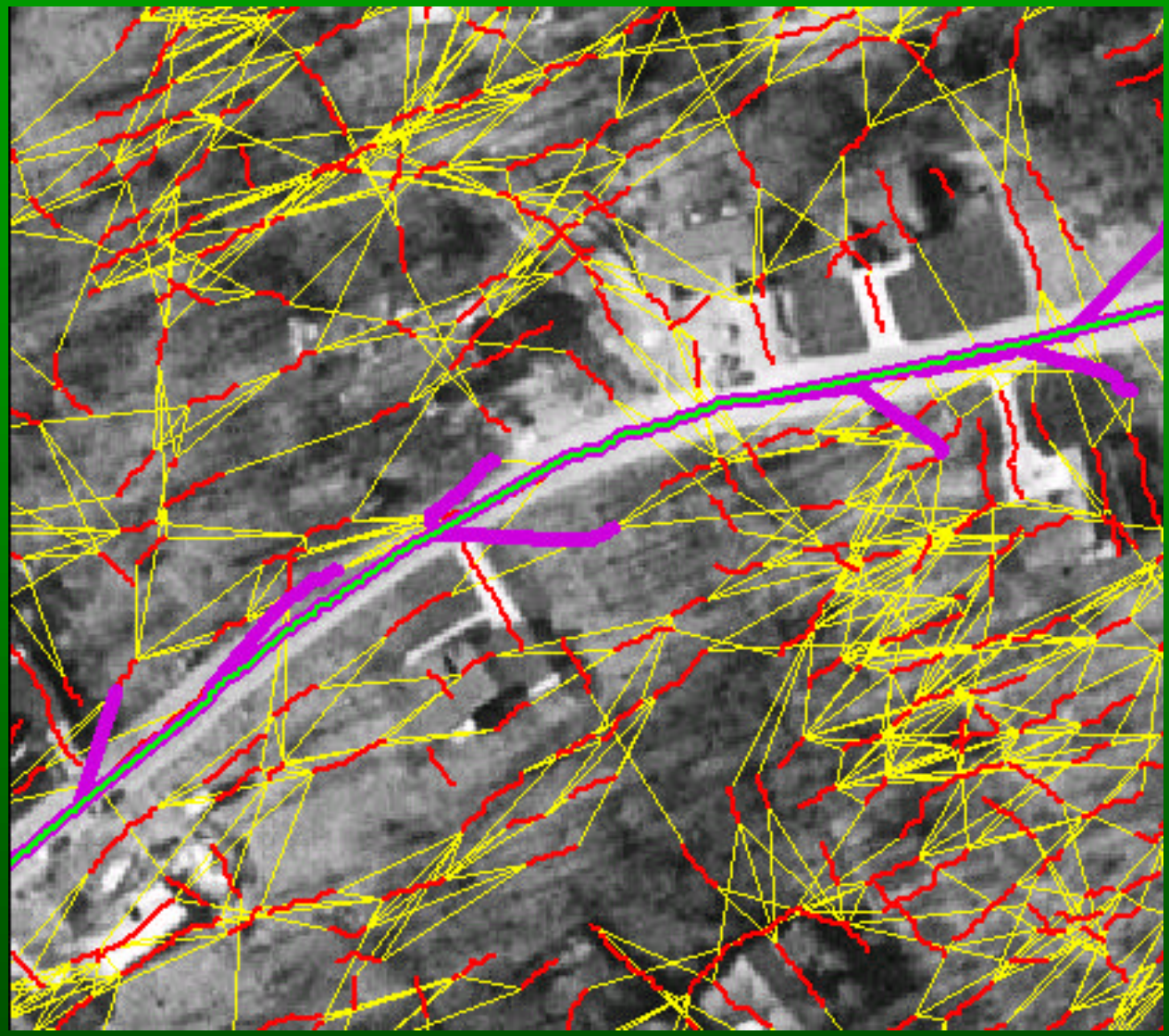


Others

Road Network Extraction



The current road extraction method utilizes two major approaches to start the extraction process: with an image or with an existing map. When starting with an image, it proceeds first with analysis of local image characteristics such as intensity, intensity change, texture and neighborhood connectivity. These characteristics, when formalized, can be used to define a local template, or a feature model. Matching the template with the image, potential features will be extracted.



Matches generated with local template usually have problems. Some of the matches may not represent an intended feature. In other situations, fragmentation can occur for detected elements. To overcome the problem, a feature network is established to group and extract intended features.

After grouping, potential road segments form hypothesized road candidate. By comparing the characteristics of a hypothesized candidate with the trained road model, identification of a candidate will be established (e.g., all the green lines on the image are identified as roads, purple lines are not).

After extraction, post-processing sometimes is necessary in order to generate smooth centerlines or to measure feature length and width.

Conclusions and Discussions

- Automated road network extraction remains a challenge problem, no existing software is able to perform the task reliably.
- Optimization method is one of the approaches toward automated road network extraction, and has been studied extensively in the field. The major contribution of the research is perhaps the concept of combining or separating the road searching and the recognition procedures. That is, during the road searching stage, road candidates are identified, and during the recognition stage, candidates are examined further for positive identification.
- From the experiment, automated road recognition is possible. The reliability is still the major issue.
- Many research problems are still out there, such as:
  - Unsupervised road recognition,
  - Changes in resolutions, image types, background, etc.,